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L6: Entry 9 of 9 File: DWPI May 7, 1997

DERWENT-ACC-NO: 1997-229238
DERWENT-WEEK: 199721

TITLE: Friction stir welding tool and method for joining workpieces together having a joint region between them - the tool having a support body to which an elongate probe with at least flattened section is mounted that is inserted in and moved along the joint while being rotated to generate frictional heat to melt material.

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PATENT-ASSIGNEE:

ASSIGNEE	CODE
WELDING INST	WELDN

PRIORITY-DATA: 1996GB-0005864 (March 20, 1996), 1995GB-0021570 (October 20, 1995), 1995GB-0023827 (November 22, 1995)

PATENT-FAMILY:

PUB-NO	PUB-DATE	LANGUAGE	PAGES	MAIN-IPC
GB 2306366 A	May 7, 1997		031	B23K020/12

APPLICATION-DATA:

PUB-NO	APPL-DATE	APPL-NO	DESCRIPTOR
GB 2306366A	October 17, 1996	1996GB-0021690	

INT-CL (IPC): B23 K 20/12; B29 C 65/06

ABSTRACTED-PUB-NO: GB 2306366A
BASIC-ABSTRACT:

Friction stir welding tool has a support body (3) to which is mounted an elongate probe (1) which, in use, extends into material to be welded on either side of a joint region and is rotated to plasticise the material while being traversed along the joint region. The probe, in cross-section, has at least one flattened section (4) such that it presents, in a plane extending along the axis of rotation, a varying diameter across the joint region during rotation.

Also claimed is a method of joining workpieces having a joint region between them using the friction stir welding tool by causing the probe of the tool, which is of a harder material than the workpiece, to enter the joint region while causing relative cyclic movement to generate frictional heat and cause the opposed portions to become plasticised, moving the probe along the joint region, and, following its removal, allowing the plasticised portions to solidify to join the workpieces together.

ADVANTAGE - The probe enables plasticised material to flow past it as it is traversed along the joint region.

CHOSEN-DRAWING: Dwg.1A/16

TITLE-TERMS: FRICTION STIR WELD TOOL METHOD JOIN WORKPIECE JOINT REGION TOOL SUPPORT BODY ELONGATE PROBE FLATTEN SECTION MOUNT INSERT MOVE JOINT ROTATING GENERATE FRICTION HEAT MELT MATERIAL

DERWENT-CLASS: A35 M23 P55

CPI-CODES: A11-C01A; M23-E01;

ENHANCED-POLYMER-INDEXING:
Polymer Index [1.1] 018 ; P0000 Polymer Index [1.2] 018 ; N9999 N6166 ; K9574 K9483 ; K9676*R ; J9999 J2915*R ; K9416 ; ND05 ; ND07

SECONDARY-ACC-NO:
CPI Secondary Accession Numbers: C1997-073604
Non-CPI Secondary Accession Numbers: N1997-189501

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9523827 22.11.1995
9605864 20.03.1996

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(51) INT CL^6
B23K 20/12, B29C 65/06

(52) UK CL (Edition O)
B3R RK R15
B5K K3A10

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WO 95/26254 A WO 93/10935 A

(58) Field of Search
UK CL (Edition O) B3R, B5K
INT CL^6 B23K, B29C
Online:WPI

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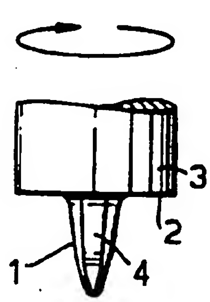
(54) **Friction stir welding**

(57) A friction stir welding tool has a support body (3) to which is mounted an elongate probe (1) which in use extends into material to be welded on either side of a joint region and which is rotted to plasticise the material while traversing along the joint region. The probe (1) has, in cross-section, at least one flattened section (4) such that during the rotational movement the probe presents, in a plane extending along the axis of rotation, a varying diameter across the joint region. Numerous other probe configurations are disclosed as also is moving the probe cyclically.

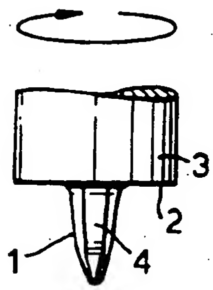
Fig.1A.



GB 2 306 366 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

Fig. 1A.



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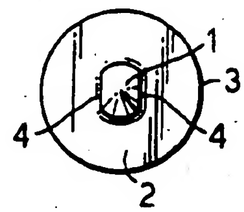

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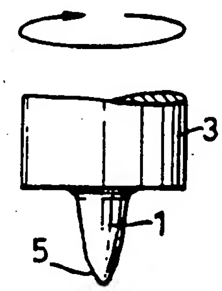

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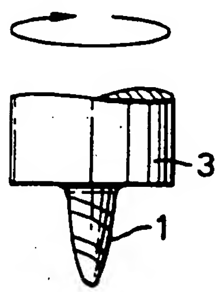

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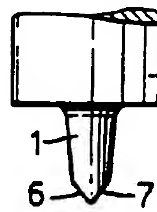

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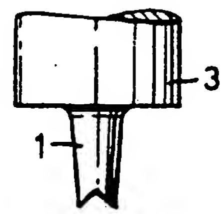

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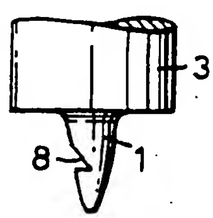

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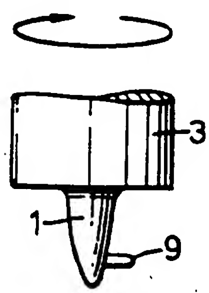
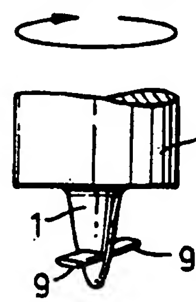


Fig. 2B.



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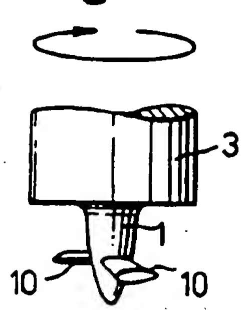

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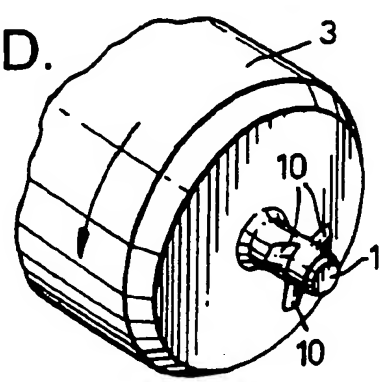

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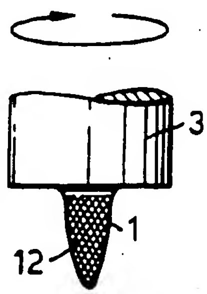

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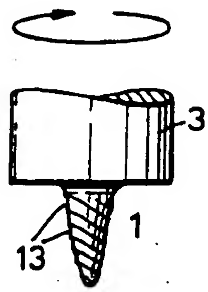

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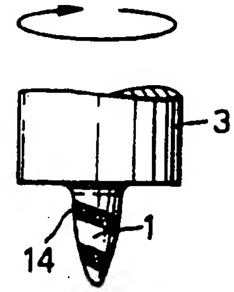

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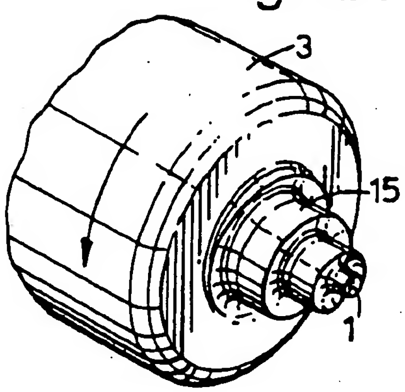

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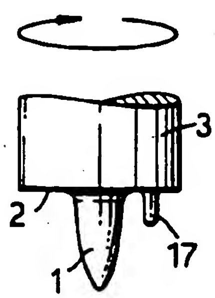

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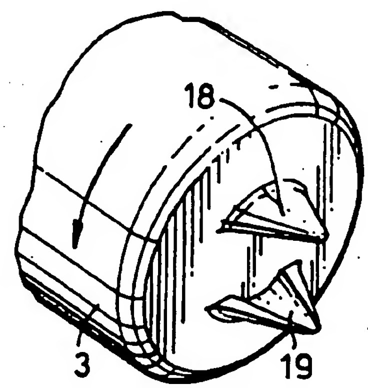

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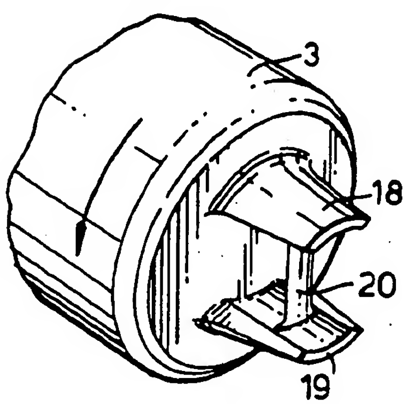

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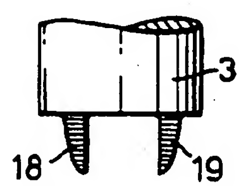

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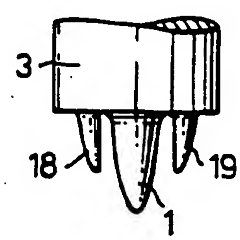

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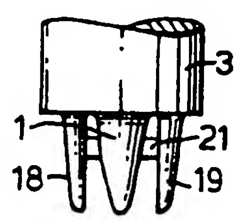

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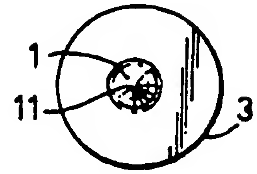

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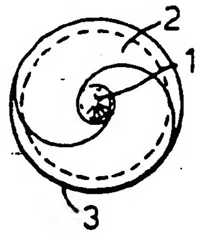

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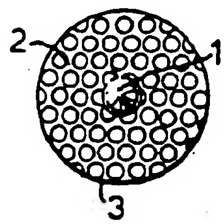

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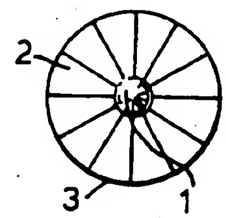

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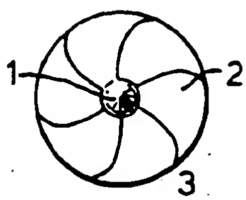

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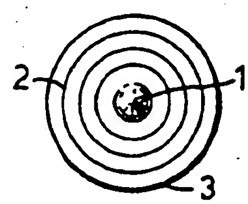

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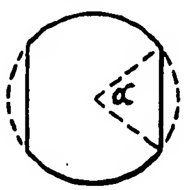
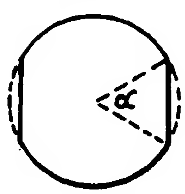


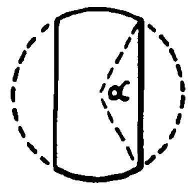
10%
α 52°

Fig.7B.



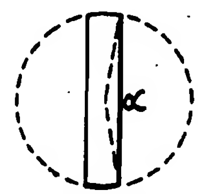
5%
36°

Fig.7C.



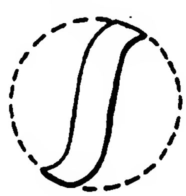
50%
120°

Fig.7D.



80%
157°

Fig.7E.



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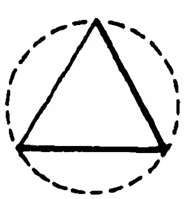

25%

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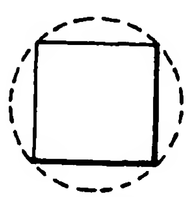

29%

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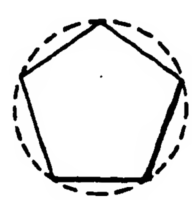
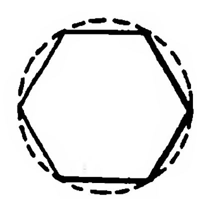


9%

Fig.8D.



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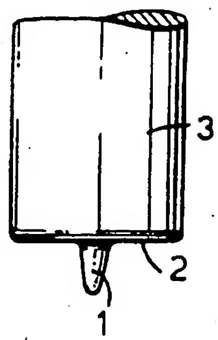

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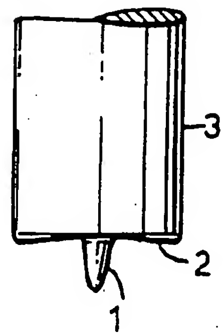

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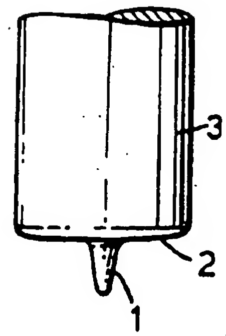
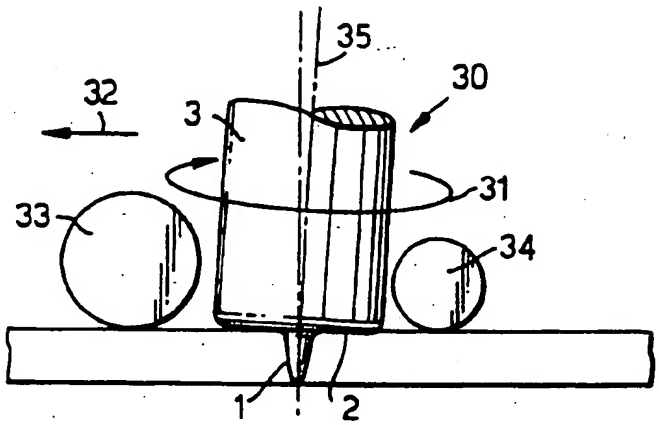


Fig.9C.

Fig.10.



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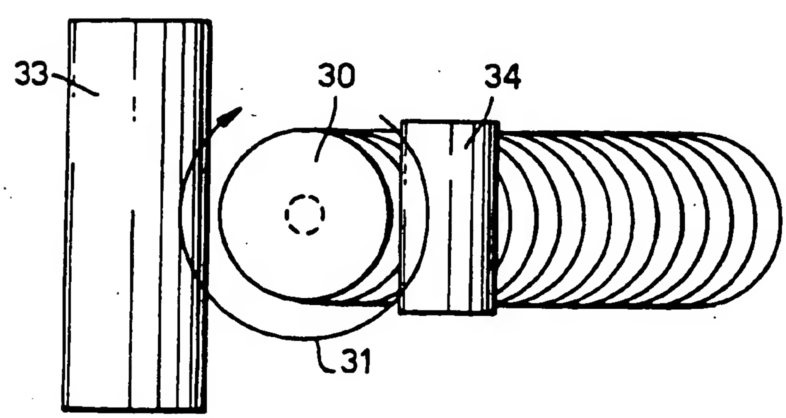
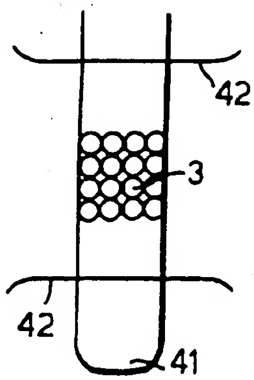


Fig. 12A.



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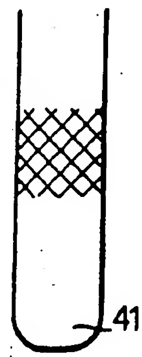
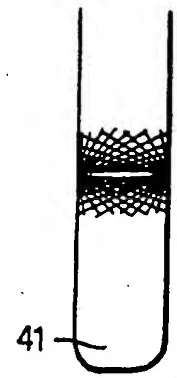


Fig. 12C.



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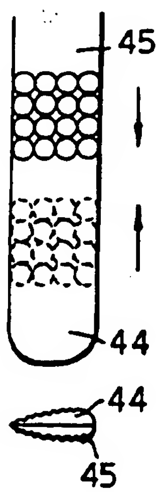


Fig. 13A.

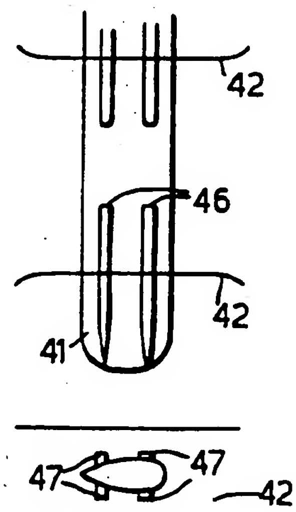
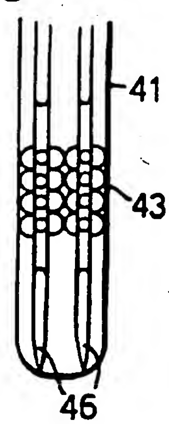


Fig. 13B.



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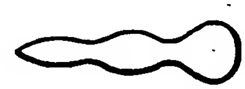


Fig. 14A.

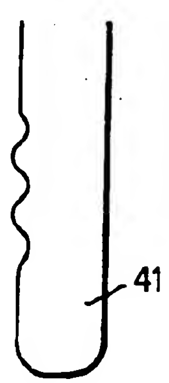


Fig. 14B.

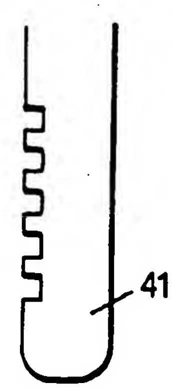
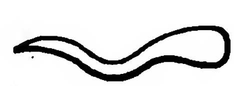


Fig. 15B.



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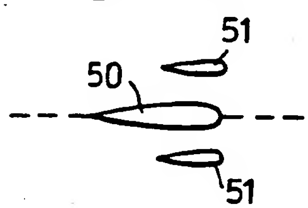

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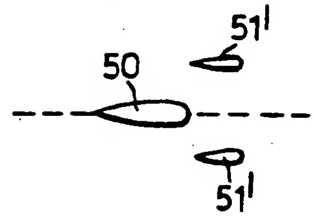


Fig.16C.

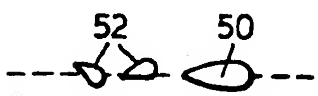
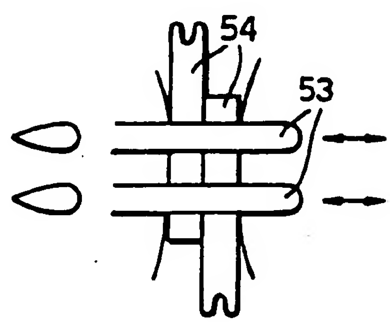


Fig.16D.



2306366

FRICTION STIR WELDING TOOL AND METHOD

The invention relates to friction stir welding and to tools for use in such welding.

Friction stir welding is described in EP-A-0615480. Typically, a friction stir welding tool has an elongate probe which is inserted into a joint region between materials to be welded, undergoes a cyclic motion to generate plasticised material and is typically traversed along the joint region although in some cases it could simply be withdrawn without traversing. This technique has been utilised not only in the butt joining of sheets but in eliminating or closing cracks in a given material and for joining together the two sides of the material to form a hollow section such as a tube. The process has been successfully applied to a wide range of materials including metals and alloys, reinforced metals such as MMCs (metal matrix composites), and thermoplastic type materials. Although commonly applied to butt joints and corner joints, the friction stir process can also be applied to lap joints especially with some designs of probe.

Although conventional probes work satisfactorily in many applications, there are some situations where improvements are required.

In accordance with one aspect of the present invention, a friction stir welding tool has a support body to which is mounted an elongate probe which in use extends into material to be welded on either side of a joint region and which is rotated to plasticise the material while traversing along the joint region, wherein the probe has, in cross-section, at least one flattened section such that during the rotational movement the probe presents, in a plane extending along the axis of rotation, a varying diameter across the joint region.

We have realised that in some applications, it is important to enable plasticised material to flow past the probe as the probe is traversed along the joint region.

With conventional probes this has not been achieved sufficiently since the probes had a symmetrical and locally constant cross-section (for example circular).

In some cases, a single flattened section (or flat) is sufficient but in other applications it is envisaged that two, three or more flattened sections could be used. In the case of three or more sections, they could define a polygon in cross-section.

Typically, the or each flattened section will extend generally along the length of the probe and in some cases along the full length of the probe. In some examples, however, the flattened section could be twisted around the surface of the probe.

In further examples, the at least one flattened section is provided only at the probe tip. Typically, this will be on an outer surface of the probe tip but it could also be formed by a V-cut into the base of the probe tip.

In yet a further example, the at least one flattened section is provided by a notch formed in the probe surface between its ends.

The flattened section in these cases provides a through path for the plasticised material, particularly in the direction of traverse along a joint line. This through path is distinguished from the situation with a simple cylindrical probe, as described in EP-A-0615480, where the plasticised material must flow around the probe. Conveniently, the through path can be compared with the dimensions of the remainder of the probe.

In accordance with a second aspect of the present invention, a friction stir welding tool has a support body to which is mounted an elongate probe having at least one laterally extending spur.

This second aspect of the present invention constitutes an extension of the first aspect since when the probe is rotated, it will, in the region of the spur, present in cross-section a varying profile across the joint region.

More than one laterally extending spur may be provided and these may or may not be symmetrically positioned about the probe, with the intervening gaps providing the through path or aperture in this region.

In accordance with a third aspect of the invention, the surface of the probe is (deeply) scarred or creviced to provide the desired varying profile in any given plane along its length. Typically, the surface is uniformly pock-marked to provide scavenging projections. Alternatively, the surface may be grooved in a spiral fashion and in some cases a combination of grooves and pock-marks used. Preferably, in all cases the spacing between edges or projections is larger than the dimension of the projection to provide the desired through path.

In accordance with a fourth aspect of the present invention, a friction stir welding tool has a first elongate projection or probe mounted on the support body offset from its axis of rotation so that the projection describes a circular path about the axis.

Typically, the tool will further comprise a second elongate projection or probe mounted to the support body. The second probe could be mounted with its axis coaxial with the rotational axis of the support body and in this case, the first probe could be shorter than the second probe.

In another embodiment, the second probe axis is also offset from the rotational axis of the support body and the two probes may or may not be symmetrically positioned relative to the rotational axis of the support body.

In a further example, a third elongate probe is mounted to the support body with its axis coincident with the rotational axis of the support body, the first and second probes being laterally offset from the third probe.

When more than one probe is provided, they may be laterally connected by one or more connection members. This provides additional support for the probes.

The at least one elongate probe can take any conventional form and may, for example, be cylindrical or have a tapered form.

In addition, the or at least one of the probes could include at least one flattened section in cross-section (as in the first aspect of the invention). Other features which could be provided on the probe include:

one or more grooves extending along or around the probe;

a corkscrew thread;

a knurled or pock-marked profile;

one or more lateral spurs or projections;

a scroll formation.

In accordance with a fifth aspect of the present invention, a friction stir welding tool has a first elongate projection or probe mounted on the support body slightly offset from the rotation axis of the support body wherein during rotational movement of the support body, the probe undergoes an orbital movement.

The fifth aspect of the present invention produces the effect of a flattened section as in the first aspect of the present invention by causing an orbital movement of the probe so that again plasticised material can flow past the probe, in the space provided by the offset of the probe.

Typically, the axis of rotation of the support body will intersect the probe.

In accordance with a sixth aspect of the present invention, we provide a friction stir welding tool having a support body to which is mounted an elongate probe which in use extends into material to be welded on either side of a joint region and which is rotated to plasticise the material while traversing along the joint region, wherein the face of the support body to which the elongate probe is attached and which rotates in use is profiled to increase the working and mixing of the material of the surfaces of the sides to be joined. This profiling may comprise

grooves, scrolls, ridges or knurling and the like and is distinguished from the smooth substantially flat, or slightly radiused surfaces of the prior art.

Typically, the probe is mounted to a generally planar surface of the support body which may be orthogonal to the probe axis. In some cases, however, the support body surface could extend in a non-orthogonal inclination relative to the probe axis.

In accordance with a seventh aspect of the present invention, a method of joining workpieces defining a joint region therebetween using a friction stir welding tool according to any of the first to sixth aspects of the invention comprises causing the probe of the welding tool, which is of a material harder than the workpiece material, to enter the joint region and opposed portions of the workpieces on either side of the joint region while causing relative cyclic movement between the probe and the workpieces whereby frictional heat is generated to cause the opposed portions to take up a plasticised condition; translating the probe along the joint region; removing the probe; and allowing the plasticised portions to solidify and join the workpieces together.

Typically, the probe extends into the joint region in a direction orthogonal to the traverse direction and in the plane of the joint region. However, in some cases it is advantageous to incline the probe so that it is at an acute angle relative to the traverse direction and/or at an acute angle relative to the plane of the joint region. Typically, the probe may be tilted in the range 1-3° from an orthogonal direction relative to the traverse direction to ensure that the forward angle between the axis of the probe and the surface of the workpiece in the direction of travel is not less than 90° and is preferably slightly greater.

In accordance with an eighth aspect of the present invention, a method of joining workpieces defining a joint region therebetween comprises causing the probe of a

friction stir welding tool, which is of a material harder than the workpiece material, to enter the joint region and opposed portions of the workpieces on either side of the joint region while causing relative cyclic movement between the probe and the workpieces whereby frictional heat is generated to cause the opposed portions to take up a plasticised condition; translating the probe along the joint region; removing the probe; applying pressure to the material downstream of the probe; and allowing the plasticised portions to solidify and join the workpieces together.

We have found that there is a significant advantage in applying pressure to the material downstream of the welding tool since it assists in consolidating the joint.

Preferably, the method further comprises applying pressure to the joint region upstream of the welding tool.

Preferably, the probe is part of a welding tool in accordance with any of the first to sixth aspects of the invention.

Some of the features of the improved rotary probes with respect to providing a through path for the plasticised material apply also to the smooth reciprocating blade disclosed in EP-A-0615480. Thus, the use of a friction stir welding tool comprising an elongate blade having a surface or edge which is not smooth has the additional advantage that the tool increases the working or mixing of such plasticised material as formed.

The surface or edge of the blade can be formed in a wide variety of ways and, for example, can include knurled or pock-marked zones, grooves, ridges or combinations of these. Alternatively or in addition, holes can be formed in the blade which allow intermixing of plasticised materials from either side of the blade in use.

In some cases, the tool comprises a pair of elongate blades positioned adjacent one another for reciprocal movement in opposite senses.

It should also be noted that the friction stir welding process has particular advantages when carried out under water. Firstly, the process can be used to weld components under water in for example sub-sea repair situations and secondly it may provide certain metallurgical advantages. For example, increased cooling rate will lead to a reduced heat affected zone and assist improvement in the physical properties with some materials.

Some examples of friction stir welding tools according to the invention will now be described with reference to the accompanying drawings, in which:-

Figures 1A-1G illustrate different examples of the first aspect of the invention;

Figures 2A-2D illustrate examples of the second aspect of the invention;

Figures 3A-3D illustrate examples of the third aspect of the invention;

Figures 4A-4F illustrate examples of the fourth aspect of the invention;

Figure 5 illustrates an example of a slightly offset, but otherwise central, cylindrical probe of the fifth aspect of the invention;

Figures 6A-6E illustrate five different examples of the sixth aspect of the invention with respect to the underside of the support body;

Figures 7A-7D illustrate the through path of probes according to Figures 1A and 1B of the first aspect of the invention;

Figures 8A-8D illustrate other multi-sided solid probes of the first aspect of the invention;

Figures 9A-9C illustrate different overall contours in side elevation of the face of the support body;

Figure 10 is a schematic side view of a welding tool during a friction stir welding process;

Figure 11 is a plan of the components shown in Figure 10;

Figures 12A-12D illustrate four different examples of blade welding tools;

Figures 13A and 13B illustrate two further examples of blade welding tools;

Figures 14A and 14B illustrate two further examples of blade welding tools having profiled edges;

Figures 15A and 15B illustrate two further examples of blade welding tools of changing lateral dimension; and,

Figures 16A-16D illustrate multiple blade configurations.

The probe 1 shown in Figure 1A and in cross-section in Figure 1B is mounted to the undersurface 2 of a support body 3. The probe 1 has a pair of flattened sections or flats 4 extending fully along its length. As can be seen, the probe also tapers towards its tip.

The conical probe 1 may be provided with two, three, five or any number of surface flats which preferably follow the taper of the original shape of the conical probe. Thus the flats 4 are smaller in section, and the edges of the flats define ridges which are closer together, towards the tip of the probe compared with those at its base. This arrangement adds to the working of the plasticised material substantially throughout the probe length as the flats serve as a blade or paddle moving through the plasticised material formed by the frictional heating.

As will be appreciated, the flats define a reduced section compared with that of a cylindrical probe, and hence an aperture or through path within the zone swept by the rotating probe. The maximum linear thickness or width of aperture provided by the flat can be expressed as a proportion of the full diameter of the probe. Thus, as illustrated in Figure 7, the total aperture presented by the two sides can range from as little as 5% (Figure 7b) through preferably not less than 10% (Figure 7a), to as much as 80% or more (Figure 7d). In practice, a total aperture of the order of 50% (Figure 7c) is beneficial compared with the simple slightly tapered cylindrical probe

of the prior art. In addition, it is noted that the flats, as well as providing a through path for the plasticised material, serve to some degree as paddles increasing the working of the plasticised material, and in particular the mixing of material from either side of the joint.

The paddle action can be further enhanced by shaping the flat surfaces such as illustrated in Figure 7e compared with Figure 7d.

Moreover, the flats can be formed as a simple multi-sided solid section instead of a cylindrical probe, as shown in Figure 8. The nominal apertures as a proportion of the circle defined by the corners of the solid sections are 25%, 29%, 9% and 13% for the 3, 4, 5 and 6 sided sections shown in Figures 8a-d respectively. It is noted that the odd numbered sections provide only a single path at the maximum position, whereas the even numbered sections provide two diametrically opposite paths simultaneously. However, the sweeping or paddle action of the flats is continuous.

The probe 1 shown in Figure 1C is provided with an angled flat 5 at its lower end. This flat serves to work the plasticised material, particularly at the root or extremity of the probe where with some materials defects can be experienced with the simple bull nosed slightly tapered conical probe.

Figure 1D is a modification of the Figure 1A example in which the flats 4 are twisted in a left hand orientation around the probe surface, to give a downward component to the paddle action.

Figure 1E is a modification of Figure 1C with two flats 6,7 extending from the tip of the probe 1. In a particularly preferred arrangement (not shown), three flats are used which come to a single point on the axis of the probe 1 which allows for more ready penetration of the workpiece from its upper surface. Figure 1F shows a similar arrangement to Figure 1E but inverted to present an inverted V-shape in cross-section while Figure 1G shows a

single flat or notch 8 where the latter serves to work the plasticised material at a particular zone with respect to the depth of the probe 1.

Figure 2A illustrates a first example of a probe according to the second aspect of the invention. In this case, a laterally extending spur or projection 9 is provided on the surface of the probe 1. In Figure 2B a pair of spurs 9 are provided and can have a partly aerofoil form as shown in Figure 2C for three projections 10 to help mix the plasticised material and in particular to give the mixed plasticised material a downward component as viewed. Figure 2D illustrates in perspective form a tool similar to Figure 2C.

Figure 3 shows examples of tools according to the third aspect of the invention.

In Figure 3A, the slightly tapered conical probe 1 is provided with a knurled or pock-marked surface 12 giving a series of hills and vales which operate to disturb the flow of the plasticised material. Preferably, the leading faces of the hills are relatively steeply formed or shear to give a paddle-like action, with the spacing between the ridges or projections significantly larger than the dimension of the projections to provide an adequate through path. This increased agitation serves to break up tenacious oxide films and the like, such as found with aluminium and its alloys.

In Figure 3B the surface of the slightly tapered conical probe 1 is provided with a continuous spiral groove or ridge 13 extending substantially to the full length of the probe. This is so orientated as to tend to drive the plasticised material in a downward direction as illustrated. Thus for rotation in the normal clockwise sense as viewed from above the spiral thread has a left hand orientation. The spiral may be of substantially constant pitch but varying radius, or may be of generally finer pitch with reducing radius towards the tip extremity

of the probe. Again, preferably the spacing between ridges is significantly large.

Figure 3C shows the probe 1 having a knurled or pock-marked surface texture arranged in a spiral with a left hand orientation such as is found on a burring tool, as shown at 14.

Alternatively, the form (not shown) of the ridges on the probe of Figure 3B can be likened to a corkscrew of the appropriate direction of rotation with respect to the orientation of the corkscrew. A further development is illustrated in perspective in Figure 3D which shows a spiral ridge or face in the form of a scroll 15 which gives a more positive downward exertion on the plasticised material compared with a simple left hand spiral groove. In Figure 3D the spiral scroll is shown in an exaggerated manner for clarity. Again the pitch of the spiral may be substantially constant or varied to reduce towards the tip.

The feature of an offset probe or projection is illustrated in the examples shown in Figures 4A-4F with or without a central conical probe. In Figure 4A an auxiliary probe or projection 17 extends from the surface 2 of the support body 3 laterally offset from a central probe 1. It will be noted that the probe 17 is shorter than the probe 1 and it will operate at a radius well exceeding the normal plasticised zone formed from the tapered conical probe 1 alone.

In Figure 4B a pair of probes or projections 18,19 extend from the support body 3 and are positioned substantially symmetrically about the rotational axis of the support body 3. The projections 18,19 generally conform as viewed from their extremities to their radial position, i.e. form part of the circular path generated by the rotation of the support body 3. This arrangement is suitable for lap joints where a substantially wide plasticised layer is required to give sufficient joint strength. In the arrangement shown, the total volume of displaced material caused by the probes is small compared

to the volume of plasticised material formed. Also, the aperture for passage of plasticised material through the tool with its traverse is relatively large. The arrangement of Figure 4B is particularly suitable for lap joints in sheet material.

Figure 4C is a modified form of the Figure 4B example in which each probe 18,19 is provided with surface marking such as grooves or ridges.

Figure 4D is a further modification of the Figure 4B example in which the probes 18,19 are supported by a simple spider 20, as shown in perspective.

In Figure 4E the probes 18,19 constitute satellites to a main central probe 1. The probes 18,19 in effect preheat plasticised material and form a plasticised ring surrounding and preferably coalescing with the normal plasticised layer provided by the central probe 1. The satellite probes 18,19 serve to increase substantially the total volume of the plasticised material without the need for a large diameter probe, as well as providing a through path. A large diameter probe in itself would displace comparatively great amounts of material and leave a substantial cavity at the end of a linear weld run or circumferential weld run.

Figure 4F is similar to Figure 4E but with the probes 18,19 extending to the full depth of the main probe 1 and being supported by a simple spider 21 connecting with the main probe 1. Preferably, the spider 21 is in the form of slightly angled extension arms which, like a fan blade or propeller screw, tend to work plasticised material in a downward direction.

Figure 5 is a cross-section taken through an example of a tool according to the fifth aspect of the invention. In this case, the axis 11 of the probe 1 is slightly offset from the rotational axis of the support body 3, in this particular case about 0.1mm. When the support body 3 is rotated, the probe 1 will undergo an orbital motion as well as a rotation and again plasticised material can flow past

the probe 1 as it is displaced while being traversed along the joint region.

The form of the probe 1 in this aspect of the invention can be of any convenient type such as the examples shown in Figure 1.

Figures 6A-6E illustrate various profiles for the face 2 as shown in plan and any of these profiles can be formed on any of the probe tools shown in Figures 1 to 5. Figure 6A illustrates a pair of complementary angled surface portions in the form of a flattened spiral. Figure 6B illustrates a knurled or pock-marked surface. Figure 6C illustrates a set of radially extending grooves while Figure 6D is a variation of Figure 6C in which the grooves have a slightly curved form. In Figure 6E a set of concentric grooves are shown. These contour details are superimposed on the overall contour of the face in side elevation. Thus, the tool shown in Figure 9A comprises a probe 1 mounted to a nominally flat face 2 of a support body 3. The probe 1 is centred on the axis of the support body 3 which rotates in use. In Figure 9B the face in side elevation has a slight concave form while the face shown in Figure 9C has a slight convex form. Any contour of Figure 6 can be used on Figure 9.

Figures 10 and 11 illustrate a friction stir welding process in which a welding tool 30 is rotated about its axis as shown at 31 while being traversed along a joint region in a direction 32. As can be seen in Figure 10, the axis of rotation 35 of the tool 30 is tilted in a slight rearward direction relative to a normal to the workpiece surface. In this way, the rearward side of the surface 2 of the tool bears on the joint region. Typically, the face 2 is some 9mm in diameter (normal to the axis of the probe 1) and is chamfered thereafter as shown in Figures 9B or 9C. With a small inclination of between 1 and 3°, the depression exerted at the rear amounts to some 0.08 to 0.25mm respectively. This assists in consolidating the joint, pressing down the plasticised material generated by

the probe 1, and providing extra material to compensate for lack of fit-up and the like.

For a controlled degree of compression, it is advantageous to set the height of the probe tool 30 with respect to the upper surface of the workpieces being joined by using guides or rollers 33,34 fore and aft of the tool respectively. The trailing roller 34 in particular is very useful in consolidating the weld. With a sufficiently rigid set up and components of known thickness, the height of the tool, in a rigid press-like machine, can be preset according to the dimensions concerned.

In addition to a rearward tilt as shown in Figure 10, the tool could also be given a lateral tilt.

Figure 12A illustrates a friction stir welding tool in the form of a blade 41 which extends through slots (not shown) in a pair of guard plates 42 between which the blade 41 is reciprocated in use and between which workpieces to be welded are located. As can be seen in Figure 12A, the blade 41 includes a knurled or pock-marked zone 43 which provides hills and dales in a portion of its length such that it both works and/or increases the amount of plasticised material compared with that formed from a simple smooth blade.

With the reciprocal motion, the knurled or pock-marked zone is displaced leaving a zone where the plasticised material can flow past the blade in the space so provided.

Alternatively or in addition, holes can be provided in the blade to promote mixing of plasticised material on either side of the blade.

Alternative blade surfaces are shown in Figures 12B and 12C where instead of a knurled zone a series of grooves in a cross hatched profile are provided. In Figure 12B the spacing between the grooves is substantially constant while in Figure 12C the grooves are oriented to provide a finer spacing towards the rear side of the blade.

In Figure 12D two blades 44,45 are shown similar to the blade 41 in Figure 12A, the blades being arranged back

to back. In use, the blades 44,45 are operated together in opposed motion with the knurling or pock-marking on one side at the opposite position to that on the other side at the extremity of the strokes.

Figure 13A shows a further variation where the blade 41 is provided with longitudinal ridges 46 of substantially constant section and of such length with suitable gaps that they pass through the guard plates 42 irrespective of the amplitude of reciprocal motion but leave spaces for plasticised material to flow through. The guard plates 42 have corresponding recesses 47 in which the longitudinal ridges 46 at the extremity of the blade locate. Figure 13A shows a simple ridge increasing the nominal width of the plasticised zone compared with the simple blade itself but leaving space for the extra material. It will also be seen in Figure 13 that the general cross-section of the blade 41 is lozenge shaped, to promote flow past the blade.

Figure 13B illustrates a blade 41 whose surface is a combination of a knurled zone 43 similar to Figure 12A and ridges 46 similar to Figure 13A. Again, the blade may be provided with through holes.

In the previous examples, the major surfaces of the blade 41 have been roughened in various ways. In the examples shown in Figures 14A and 14B the rear edge of the blade 1 is formed with a wavy profile (Figure 14A) or a serrated profile (Figure 14B). In these examples, the central regions of the wavy and serrated edges can be bent to give a degree of paddle like action to increase the mixing of the plasticised material on either side of the joint line. This is particularly useful for thermoplastics which tend to form a surface skin and hence impede the growth of molecular chains across the joint line.

These several variations lead to improved productivity in greater reliability of joining, reduced tendency for flat spots or pores in the joint area and a wider tolerance in operating conditions.

The blades shown in Figures 12 and 13 have a non-smooth surface and can have a lozenge cross-section, or they could have parallel sides. Alternatively, as shown in Figure 15A, the blade could be in the form of a series of ripples in cross-section while in Figure 5B the amplitude of the ripple is larger than the thickness of the blade giving a wavy appearance in cross-section.

Furthermore, the blades shown in Figure 15 could have any of the roughened forms shown in Figures 12 to 14.

Typically, the blade or blades extend into the joint region in a direction orthogonal to the traverse direction and in the plane of the joint region. However, in some cases it is advantageous to incline the blade or blades at an acute angle relative to the traverse direction and/or at an acute angle relative to the plane of the joint region. Typically, the blade or blades may be tilted in the range 10-30° from an orthogonal direction relative to the traverse direction to ensure that the forward angle between the axis of reciprocal motion of the blade and the surface of the workpiece in the direction of travel is significantly less than 90°, with the guard plates 42 oriented accordingly. The roughened or non-smooth zones are also skewed to suit.

The invention also envisages a modified friction stir welding process in which additional reciprocating blades are used in conjunction with the principal blade which traverses along the common joint seam. This is shown in Figure 16. In Figure 16A, the main blade 50 is accompanied by two smaller blades 51 set on either side to increase the volume of plasticised material. This is particularly useful for joint seams which are not closely fitted together or where it is difficult to maintain exact positioning of the blade with respect to the joint seam along its length. The supplementary reciprocating blades increase the volume of plasticised material without substantially increasing the total displaced material caused by the blade traversing along the joint seam.

The supplementary blades 51′ can be considered for pre-heating the joint and plasticised material in the arrangement shown in Figure 16B where the spaced blades travel in the substrate material on either side of the joint line and upstream of the main blade 50.

A further arrangement is shown in Figure 16C where supplementary blades 52 downstream of the main blade 50 are used to work the common plasticised material formed from the substrate on either side of the joint line. Preferably, the supplementary blades 52 are so angled to increase the working of the plasticised material and hence assist in overcoming a tendency for surface films to prevent full molecular development across the joint seam.

In Figure 16D the principal blade has been replaced by two outrigger blades 53 extending through workpieces 54. This is preferred for lap joint type applications where a considerable volume of plasticised material is needed to give a sufficient section in the interface zone as illustrated without using a large sized blade which itself would displace a considerable amount of material.

These several variations lead to improved productivity in greater reliability of joining, reduced tendency for flat spots or pores in the joint area and a wider tolerance in operating conditions.

A wide range of materials can be successfully joined including thermoplastics, soft metals such as lead or zinc, light alloys such as aluminium alloys, and other non-ferrous metals such as copper, silver and gold, as well as materials of yet higher melting points (in excess of 1100°C) such as ferrous metals and alloys, which latter require probes of high grade temperature resisting materials such as nimonics or even certain ceramics.

CLAIMS

1. A friction stir welding tool having a support body to which is mounted an elongate probe which in use extends into material to be welded on either side of a joint region and which is rotated to plasticise the material while traversing along the joint region, wherein the probe has, in cross-section, at least one flattened section such that during the rotational movement the probe presents, in a plane extending along the axis of rotation, a varying diameter across the joint region.

2. A tool according to claim 1, wherein the or each flattened section extends along the full length of the probe.

3. A tool according to claim 1 or claim 2, wherein the flattened section is twisted around the surface of the probe.

4. A tool according to claim 1, wherein the at least one flattened section is provided only at the probe tip.

5. A tool according to claim 1, wherein the at least one flattened section is provided by a notch formed in the probe surface between its ends.

6. A friction stir welding tool having a support body to which is mounted an elongate probe having at least one laterally extending spur.

7. A tool according to claim 6, the tool having more than one laterally extending spur.

8. A tool according to claim 7, wherein the laterally extending spurs are positioned substantially symmetrically about the probe.

9. A tool according to any of claims 6 to 8, wherein the or each spur is aerodynamically shaped in cross-section.

10. A friction stir welding tool having a support body to which is mounted an elongate probe which in use extends into material to be welded on either side of a joint region and which is rotated to plasticise the material while

traversing along the joint region, wherein the surface of the probe is scarred or creviced.

11. A friction stir welding tool according to any of claims 1 to 9 and claim 10.

12. A friction stir welding tool having a first elongate projection or probe mounted on the support body offset from its axis of rotation so that the projection describes a circular path about the axis.

13. A tool according to claim 12, further comprising a second elongate probe mounted to the support body.

14. A tool according to claim 13, wherein the second probe is mounted with its axis coaxial with the rotational axis of the support body.

15. A tool according to claim 14, wherein the first probe is shorter than the second probe.

16. A probe according to claim 13, wherein the second probe axis is also offset from the rotational axis of the support body.

17. A tool according to claim 16, wherein the two probes are symmetrically positioned relative to the rotational axis of the support body.

18. A tool according to claim 16 or claim 17, further comprising a third elongate probe mounted to the support body with its axis coincident with the rotational axis of the support body, the first and second probes being laterally offset from the third probe.

19. A tool according to any of claims 13 to 18, wherein the probes are laterally connected by one or more connection members.

20. A friction stir welding tool having a first elongate projection or probe mounted on the support body slightly offset from the rotation axis of the support body wherein during rotational movement of the support body, the probe undergoes an orbital movement.

21. A tool according to claim 20, wherein the axis of rotation of the support body intersects the probe.

22. A friction stir welding tool having a support body to which is mounted an elongate probe which in use extends into material to be welded on either side of a joint region and which is rotated to plasticise the material while traversing along the joint region, wherein the face of the support body to which the elongate probe is attached and which rotates in use is profiled to increase the working and mixing of the material of the surfaces of the sides to be joined.

23. A tool according to claim 22, wherein the profile comprises a pair of complementary angled surface portions.

24. A tool according to claim 22, wherein the profile comprises a knurled surface.

25. A tool according to claim 22, wherein the profile comprises a set of radially extending grooves.

26. A tool according to claim 25, wherein the grooves have a varying radius of curvature.

27. A tool according to claim 25 or claim 26, wherein the grooves are substantially symmetrically positioned around the probe.

28. A tool according to claim 22, wherein the profile comprises a set of concentric grooves.

29. A tool according to any of claims 12 to 19 and any of claims 6 to 9; or according to any of claims 12 to 19 and any of claims 1 to 5; or according to any of claims 6 to 9 and any of claims 1 to 5; or according to any of claims 22 to 28 and any of claims 1 to 19, or according to any of claims 20 and 21 and any of claims 1 to 19 or 22 to 28.

30. A method of joining workpieces defining a joint region therebetween using a friction stir welding tool according to any of the preceding claims, the method comprising causing the probe of the welding tool, which is of a material harder than the workpiece material, to enter the joint region and opposed portions of the workpieces on either side of the joint region while causing relative cyclic movement between the probe and the workpieces whereby frictional heat is generated to cause the opposed

portions to take up a plasticised condition; translating the probe along the joint region; removing the probe; and allowing the plasticised portions to solidify and join the workpieces together.

31. A method of joining workpieces defining a joint region therebetween, the method comprising causing the probe of a friction stir welding tool, which is of a material harder than the workpiece material, to enter the joint region and opposed portions of the workpieces on either side of the joint region while causing relative cyclic movement between the probe and the workpieces whereby frictional heat is generated to cause the opposed portions to take up a plasticised condition; translating the probe along the joint region; removing the probe; applying pressure to the material downstream of the probe; and allowing the plasticised portions to solidify and join the workpieces together.

32. A method according to claim 31, further comprising applying pressure to the joint region upstream of the probe.

33. A method according to any of claims 30 to 32, further comprising inclining the probe so that it is at an acute angle relative to the traverse direction and/or at an acute angle relative to the plane of the joint region.

34. A method according to claim 33, wherein the probe is tilted in the range 1-3° from an orthogonal direction relative to the traverse direction to ensure that the forward angle between the axis of the probe and the surface of the workpiece in the direction of travel is not less than 90° and is preferably slightly greater.

35. A method according to any of claims 30 to 34, wherein the probe is part of a welding tool according to any of claims 1 to 29.

36. A friction stir welding tool comprising an elongate blade having a surface or edge which is not smooth.

37. A tool according to claim 36, wherein the surface of the blade includes one or more of knurled zones, grooves, ridges, or combinations of these.

38. A tool according to claim 36 or claim 37, further comprising a second elongate blade having a surface or edge which is not smooth, the blades being positioned adjacent one another for reciprocal movement in opposite senses.

39. A method of joining workpieces defining a joint region therebetween using a friction stir welding tool according to any of claims 36 to 38, the method comprising causing the blade of the welding tool, which is of a material harder than the workpiece material, to enter the joint region and opposed portions of the workpieces on either side of the joint region while causing relative cyclic movement between the blade and the workpieces whereby frictional heat is generated to cause the opposed portions to take up a plasticised condition; translating the blade along the joint region; removing the blade; and allowing the plasticised portions to solidify and join the workpieces together.

40. A method of joining workpieces defining a joint region therebetween, the method comprising causing a set of blades of material harder than the workpiece material to enter the joint region and opposed portions of the workpieces on either side of the joint region while causing relative cyclic movement between the blades and the workpieces whereby frictional heat is generated to cause the opposed portions to take up a plasticised condition; translating the blades along the joint region; removing the blades; and allowing the plasticised portions to solidify and join the workpieces together.

41. A method according to claim 40, wherein the set of blades comprise a central main blade and a pair of additional blades positioned laterally on either side of the main blade.

42. A method according to claim 40, wherein the blades comprise a main blade and a pair of additional blades positioned upstream of the main blade.

43. A method according to any of claims 40 to 42, wherein the blades include a pair of blades positioned downstream of the main blade.

44. A method according to any of claims 40 to 43, wherein at least one of the blades is in the form of a series of ripples in cross-section.

45. A method according to any of claims 40 to 44, further comprising inclining the blade or blades at an acute angle relative to the traverse direction and/or at an acute angle relative to the plane of the joint region.

46. A method according to claim 45, wherein the blade or blades are tilted in the range 10-30° from an orthogonal direction relative to the traverse direction to ensure that the forward angle between the axes of the blades and the surface of the workpiece in the direction of travel is less than 90° and is preferably substantially less.

47. A method according to any of claims 30 to 46, wherein the method is performed under water.

48. A method of joining workpieces defining a joint region substantially as hereinbefore described with reference to any of the examples shown in the accompanying drawings.

49. A friction stir welding tool substantially as hereinbefore described with reference to any of the examples shown in the accompanying drawings.

The Patent Office

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Claims searched:	1-5,30	**Date of search:**	6 January 1997

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Search Report under Section 17

Databases searched:

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UK Cl (Ed.O): B3R,B5K

Int Cl (Ed.6): B23K,B29C

Other: Online:WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	WO 95/26254 A (NORSK HYDRO)	
A	WO 93/10935 A (WELDING INSTITUTE)	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.